

OPERANT HOARDING: A NEW PARADIGM FOR THE STUDY OF SELF-CONTROL

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In the first of four experiments, rats were exposed to a modified multiple continuous reinforcement-extinction schedule during 15-min daily sessions. In one condition (saves condition) with the cuelight on, a single lever press produced a food pellet, briefly extinguished the cuelight, and started a clock. Saves (additional lever presses with interresponse times less than 1 s) produced an additional food pellet, briefly extinguished the cuelight, and restarted the interresponse time clock. The cuelight was extinguished 1 s after the last lever press and remained off during a 10-s period of extinction, during which no food pellets were delivered. In the other condition (savings account condition), the contingencies were the same except that the cuelight was extinguished and was not reilluminated after the initial lever press, and the delivery of all food pellets in the reinforcement component was delayed until the onset of extinction. In both conditions, rats made saves, but mean saves (total saves divided by the number of reinforcement components) were slightly reduced in the savings account condition. In Experiment 2, using six equally spaced 15-min sessions per day on alternate days, saves were either followed immediately with food and brief cuelight offset (saves condition) or were not reinforced at all. Mean saves were much greater when saves were reinforced. In Experiment 3, during 5-min daily sessions, saves earned a single pellet (savings account condition) or a number of pellets equal to the ordinal number of the lever press (interest condition). Rats made fewer mean saves, with little change in the food rate, when saves earned interest. In Experiment 4, the rats earned all their food in the operant situation during 24 daily 5-min sessions, these separated by 55-min intersession intervals during which no food was available; otherwise, the conditions were the same as in Experiment 3. In Experiment 4, the shift to interest for saves led to an increase in mean daily mean saves (total daily mean saves divided by the number of daily sessions) as well as to an increase in the number of food pellets delivered in each session. The results are discussed in terms of self-control and behavioral economics.

Key words: self-control, delayed reinforcement, amount of reinforcement, behavioral economics, saves, open economy, closed economy, lever press, rats

EXPERIMENT 1

Killeen (1974) observed that rats often pressed a lever two or three times on a continuous reinforcement (CRF) schedule before venturing to the food cup to obtain the earned pellets. In a subsequent study of the phenomenon, he found that the farther the lever was located from the food cup, the greater the number of presses the rat made before approaching the food cup.

The present study resulted from a similar serendipitous observation. Due to a program-

ming error, it was possible for a rat on a multiple fixed-ratio 10 extinction (multiple FR 10 EXT) schedule to keep the schedule in the high-reinforcement-density FR component by pressing the lever again immediately instead of collecting the pellet following the 10th lever press. The rat made repeated runs of 10 lever presses, always leaving the pellets in the tray. When the extinction component finally occurred, because the rat went to the food tray instead of pressing the lever, the rat spent most of that period eating the accumulated cache of pellets. The purpose of Experiment 1 was to determine whether this operant hoarding phenomenon could be replicated and, if so, to explore further its parameters.

METHOD

Subjects

Three albino rats of the Wistar strain were maintained at 80% of their ad-lib weights by restricting their access to food. (They had un-

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limited access to water.) The rats had been used in previous free-operant procedures and were housed in individual cages.

Apparatus

A standard student-model Gerbrands operant chamber (internal dimensions of 20 cm by 23 cm by 19 cm high) was used. The feeder wall contained a lever mounted horizontally midway between the two side walls, its center 7.5 cm above the floor. A force of about 4.4 N was required to press the lever completely. The feeder tray was located in the lower left corner of the feeder wall and could be reached through an opening (4.5 cm by 4.5 cm) in the feeder wall. The center of the opening was located about 9.0 cm from the center of the lever. A cuelight was located 16 cm above the feeder tray. A Gerbrands pellet dispenser delivered 0.045 g Noyes dry mash pellets to the feeder tray. All experimenter-controlled events were programmed by a Commodore 64® computer, which also recorded all pertinent data.

Procedure

The rats were given daily sessions of a modified multiple continuous reinforcement-extinction (multiple CRF EXT) schedule with the cuelight on during CRF and off during EXT. Each session began with a CRF component, and the components alternated as described below. Failure of the cuelight to be reilluminated 15 min after the onset of the session signaled the end of the session. Phase changes were made only when visual inspection showed that relatively stable baselines had been achieved.

Phase 1. During Phase 1 (saves condition) the first lever press during any CRF component produced a food pellet, briefly extinguished the cuelight, and in the absence of any additional lever presses, again extinguished the cuelight 1 s later to begin the EXT component. After 10 s, the cuelight was reilluminated to signal the onset of CRF and begin a new cycle. Following the first lever press in any CRF component, each additional lever press with an interresponse time (IRT) less than 1 s delivered an additional food pellet, briefly extinguished the cuelight, and delayed the onset of the EXT component until 1 s after the last such press. These additional lever presses were termed *saves*. Thus, in each CRF component,

a single unrestricted lever press was followed not only by a food pellet but also by the opportunity to make saves, these also followed by food pellets. The restriction of the maximum IRT permitted for a save to less than 1 s ensured that the rat did not have time to consume any of the food pellets produced in a CRF component until after the last save.

Phase 2. During Phase 2 (savings account condition) the same conditions were in effect except that pellets earned by either the initial CRF lever press or by subsequent saves were not delivered immediately to the tray but were instead "banked" by incrementing a counter and were delivered sequentially at 0.5-s intervals starting 1 s after the last save (during EXT). In addition, the cuelight was extinguished by the initial CRF lever press and was not reilluminated until the start of the next CRF component. The purpose of this manipulation was to eliminate all immediate stimulus consequences for saves.

Phase 3. Phase 3 consisted of a reversal to the conditions of Phase 1 with pellets delivered as they were earned.

Phase 4. Phase 4 consisted of a reversal to the conditions of Phase 2 with pellets banked for delivery at the end of each CRF component.

RESULTS

Observation of the rats on various occasions failed to reveal a single instance in which a rat obtained a food pellet from the tray and then returned to the lever in time to make a save. In fact, these observations failed to reveal any attempt to obtain a pellet in this fashion. Moreover, the observed durations of the IRTs for lever presses that were saves were usually well short of the maximum 1 s permitted. Four sessions (one session, selected at random from each of the four phases) yielded a mean median IRT of 0.34 s ($SD = 0.07$) for Rat 2 and 0.30 s ($SD = 0.07$) for Rat 3.

The primary dependent variable presented in these experiments is *mean saves*, which is the total number of saves in a session divided by the number of cycles of the CRF component in the session. Thus, mean saves represent the average number of saves per component in a session. This statistic was used rather than total saves because the number of CRF components per session was variable. Although the duration of the EXT component was time based, the length of a CRF component de-

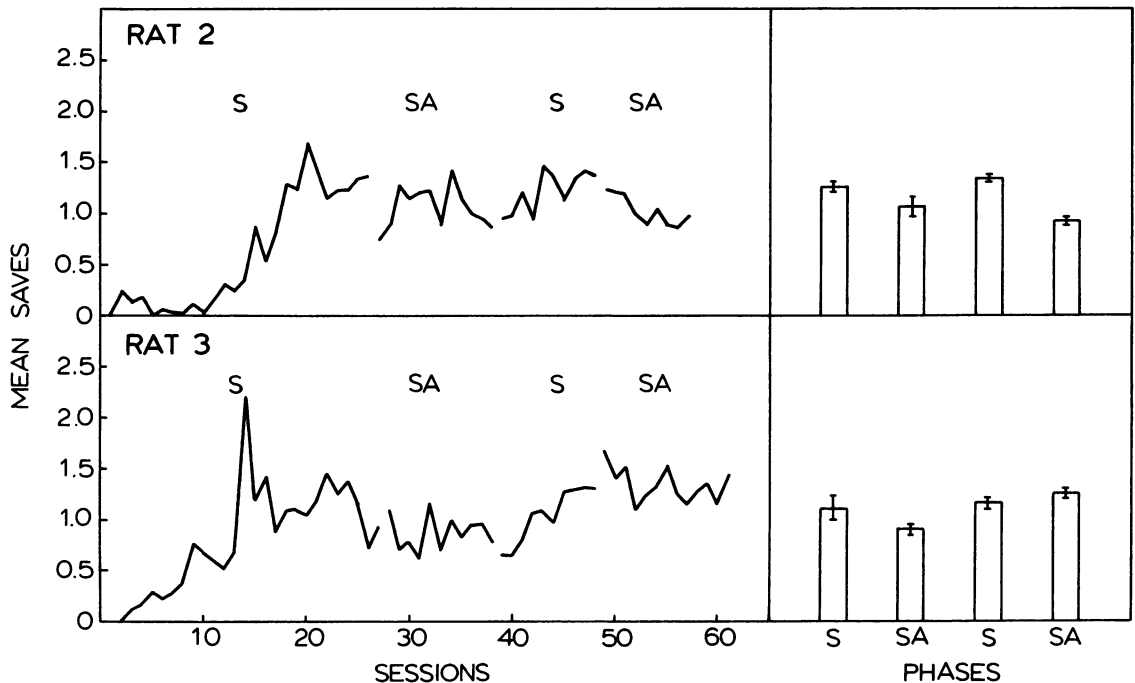


Fig. 1. Mean saves as a function of whether saves were reinforced immediately (S) or food pellets were accumulated in a savings account (SA) in Experiment 1. Sessional data are presented in the left panels, and the phase means from the last five sessions of each phase are presented in the right panels. The vertical lines in the right panels represent the standard errors of the mean.

pendent on the rat's behavior. Both the duration of the pause preceding the first CRF lever press and the number of saves made in a CRF component affected the length of each CRF component and, hence, the number of CRF components possible in a 15-min session. The choice of mean saves as the main dependent variable facilitates comparisons among sessions, phases, and experiments.

Mean saves as a function of sessions are shown in Figure 1. Only the data from Rats 2 and 3 are shown because Rat 1 failed to make any saves, even after 25 sessions. Rats 2 and 3 made about 1.2 saves per component (mean saves) in Phases 1 and 3. There was considerable variation, however, with no saves in some components and runs of up to five or six saves in others. In assessing the relatively small value of this statistic, it should be noted that the rat was not required to make any saves at all in this schedule. When reinforcers were banked in Phases 2 and 4, there was a slight decrease in mean saves, except for Rat 3 in Phase 4.

Somewhat more complete data appear in Table 1, which contains phase means, based

on the last five sessions in each phase, for lever presses, total saves, mean saves, CRF cycles, and food deliveries. These data reveal fairly small and not very consistent effects for both lever presses and total saves. Both of these variables declined slightly for both Rats 2 and 3 from Phase 1 to Phase 2. For Rat 2, there was no reversal for either lever pressing or total saves in Phase 3, but both declined again in Phase 4. For Rat 3, on the other hand, both lever presses and total saves reversed in Phase 3 but neither declined in Phase 4. Only CRF cycles showed a consistent effect, with no change for either rat as a result of the banking procedure.

DISCUSSION

The savings effect originally observed in the multiple FR 10 EXT schedule was clearly replicated, although the contingency is subtle and may not always be effective. The response rate of Rat 1 was much lower than that of the other 2 rats, and as a result there may have been an insufficient number of short IRTs to make contact with the contingency likely.

One way to view the present results is in

Table 1

Experiment 1: phase means based on the last five sessions in each phase. Data are sessional totals, except in the case of mean saves. Standard errors are in parentheses.

Rat	Phase	Lever presses	Total saves	Mean saves	CRF cycles	Food pellets
2	1	135.4 (8.0)	75.6 (6.1)	1.26 (0.08)	59.8 (2.6)	135.4 (8.0)
	2	122.4 (6.4)	62.8 (5.8)	1.07 (0.19)	59.6 (5.9)	122.4 (6.4)
	3	117.4 (6.9)	66.8 (2.6)	1.33 (0.09)	50.6 (4.8)	117.4 (6.9)
	4	104.4 (8.9)	50.4 (5.8)	0.93 (0.06)	54.0 (3.4)	104.4 (8.9)
3	1	134.8 (18.2)	70.4 (16.3)	1.09 (0.23)	64.4 (2.4)	134.8 (18.2)
	2	121.6 (6.2)	57.2 (5.5)	0.89 (0.08)	64.4 (1.6)	121.6 (6.2)
	3	141.4 (7.2)	77.6 (5.8)	1.22 (0.13)	63.8 (4.9)	141.4 (7.2)
	4	138.6 (9.7)	77.6 (7.6)	1.27 (0.11)	61.0 (3.2)	138.6 (9.7)

terms of self-control. In one of the early demonstrations of experimental self-control, Ainslie (described by Rachlin, 1970, pp. 186–188) used pigeons. Self-control was demonstrated when the pigeon refrained from pecking the key during periodic 2.5-s intervals when the key was red, thus gaining a 4-s access to grain, delayed until the termination of the red key. Impulsivity was demonstrated when the pigeon pecked the key while it was red, thus obtaining an immediate but shorter 1.5-s access to the grain. The pigeons tended to act impulsively, pecking the key while it was red. Ainslie also showed, however, that when the red key was preceded by an 11-s white key, a peck on which prevented the key from turning red at the scheduled time, the pigeons pecked the white key, demonstrating self-control and obtaining the larger delayed reward.

Rachlin and Green (1972) refined the procedure by removing the basic asymmetry involved when self-control is demonstrated by one response (not responding) and impulsivity is demonstrated by another (pecking the key). They used a concurrent-chains schedule in which pecking one of two keys in the first link provided access to a second link in which there was, after T s, an opportunity to make a choice between an immediate 2-s reinforcer and a 4-s reinforcer delayed by 4 s by pecking one of two keys. Pecking the other first-link key provided access to a second link in which there

was, after T s, an opportunity to peck a key for the delayed larger reinforcer only. When forced into the second link, which offered the choice between the larger delayed and the smaller immediate reinforcer, the pigeons almost invariably behaved impulsively, choosing the smaller and immediate reinforcer. When making a choice between the initial links, however, the pigeons showed an increasing tendency toward self-control as T increased, choosing the second link that offered only the larger and more delayed reinforcer. Thus, Rachlin and Green (1972) replicated the original findings of Ainslie using a symmetrical choice procedure.

Since the initial demonstrations of self-control, a number of studies (cf. Ainslie & Herrnstein, 1981; Fantino, 1966; Green, Fisher, Perlow, & Sherman, 1981; Logue & Mazur, 1981; Logue, Rodriguez, Peña-Correal, & Mauro, 1984; Mazur & Logue, 1978; Navarick & Fantino, 1976) have confirmed that as the delay to the smaller and relatively less delayed of two reinforcers increases, impulsivity gives way to self-control. For a more complete review of the self-control literature, the reader may consult Ainslie (1975).

Experiment 1 resembles Ainslie's original study in its asymmetry of response. In the case of the present paradigm, however, self-control was demonstrated by responding and impulsivity by not responding. Possibly, this partic-

ular asymmetrical arrangement favors self-control in a situation in which impulsivity is the usual outcome; that is, one in which the choice is made with the smaller immediate reinforcer imminent. The presence of food in the tray may motivate responding as opposed to nonresponding. However, the fact that there was little reduction in mean saves when the delivery of all reinforcers was delayed until the onset of EXT in the banking procedure used in Phases 2 and 4 suggests otherwise. Although it is the asymmetrical aspect of the procedure, coupled with the IRT restriction, that makes this series of experiments particularly interesting, the problem of asymmetry will have to be solved if the procedures are to form the basis of a new paradigm for the study of self-control. One obvious solution is to require a press on a second lever to provide access to the food tray. The continued emergence of self-control in the form of saves in such an arrangement would focus attention on some feature of the paradigm other than asymmetry (e.g., the IRT restriction).

Based on research showing the effect of a precommitment response on self-control, the switch to the banking procedure in Phases 2 and 4 of the present experiment might have been expected to lead to an increase in self-control expressed as an increase in the mean number of saves. The effect of delaying delivery of all reinforcers until the end of the CRF component is equivalent to moving the choice point backward in time. Yet, in Experiment 1, the effect of delaying reinforcement was to decrease slightly the number of mean saves. Loss of conditioned reinforcement provides one possible explanation for this result. In Phases 1 and 3, saves produced not only food but also the click of the feeder and a brief offset of the cuelight. Both of these later stimuli should have become conditioned reinforcers by virtue of being paired with food (Skinner, 1938). In Phases 2 and 4, lever presses in addition to the initial CRF lever press (saves) resulted in no immediate stimulus consequences of any sort. The loss of conditioned reinforcement might have been expected to suppress all lever presses, including saves, and the result of these two opposing processes could have been little change in mean saves. Wallace, Osborne, Norborg, and Fantino (1973) showed that pigeons would peck a key for food, even in the presence of free food, when the key peck illuminated

the hopper, darkened the key, made a click, and turned off the houselight, as well as raising the hopper. Few pecks occurred when the key pecks only raised the hopper and entries to the free-food tray produced the stimulus changes referred to above. Further research is needed to clarify the role of conditioned reinforcement in the present paradigm.

EXPERIMENT 2

One important question arising from this effect is whether the responses termed saves observed in Experiment 1 represented an operant response to a true contingency or were merely the result of a sort of behavioral momentum generated by the CRF schedule. Experiment 2 was undertaken to replicate the effect and compare the occurrence of saves when such responses are followed immediately by food and brief cuelight offset, as they were in Experiment 1, with that observed when saves are not reinforced at all.

METHOD

Subjects

Two albino rats of the Wistar strain were maintained at 80% of their ad-lib weights as in Experiment 1. The rats had been used in previous free-operant procedures not connected with the present series of experiments and were housed in individual cages.

Apparatus

The apparatus used in Experiment 2 was the same as that employed in the first experiment except for the chamber. The chamber was similar to that used in the first experiment, also being manufactured by Gerbrands, but with interior dimensions of 29 cm by 23 cm by 19 cm high. The chamber had two levers, mounted on either side of the feeder wall, their centers 8.5 cm above the floor and 11.5 cm from the left and right side walls. Only the left lever, which required a force of about 4.4 N to depress completely, was operable; the right lever was immobilized. The feeder was centered on the feeder wall just above the floor and was reached through an opening (2.5 cm wide by 3.0 cm). The distance from the center of the left lever to the center of the feeder opening was about 7.5 cm. The cuelight was

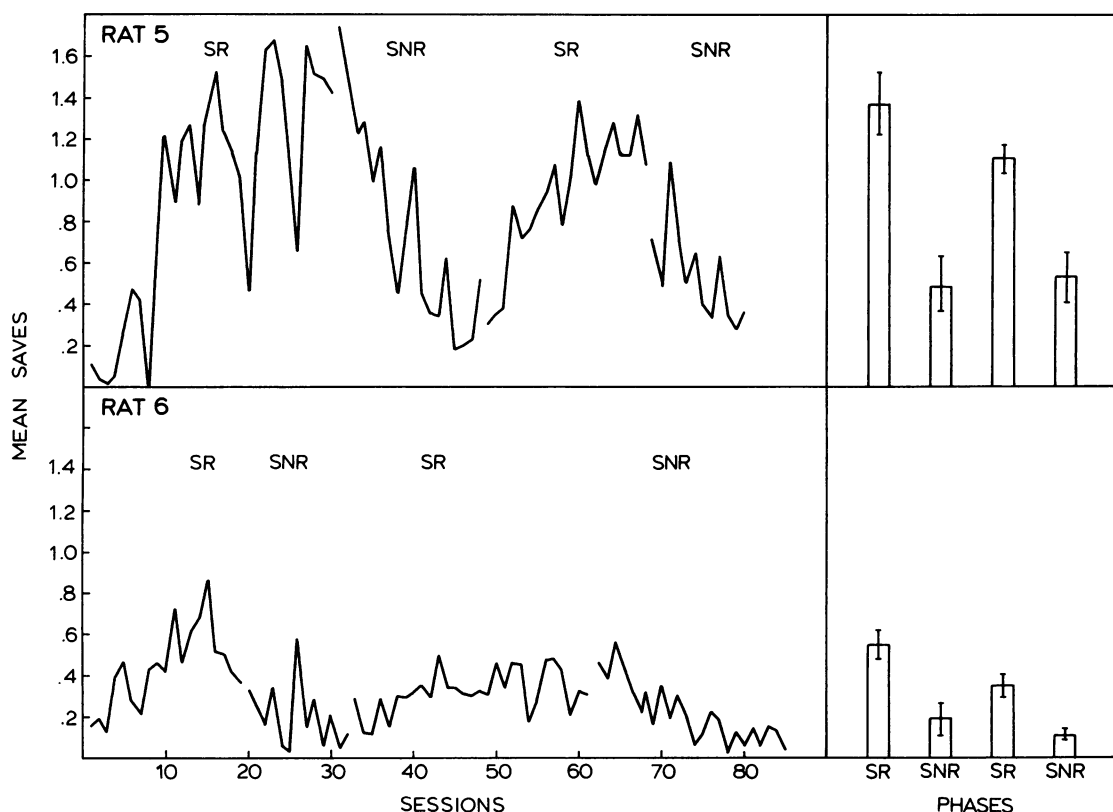


Fig. 2. Mean saves as a function of whether saves were reinforced (SR) or not reinforced (SNR) in Experiment 2. Sessional data are presented in the left panels, and the phase means from the last 10 sessions of each phase are presented in the right panels. The vertical lines in the right panels represent the standard errors of the mean.

located 14 cm above the floor and directly over the feeder opening.

Procedure

The rats were tested on alternate days, and the rat not being tested remained in its home cage with sufficient food to maintain it at 80% of its free-feeding body weight. On a testing day, the rat remained in the operant chamber and was exposed to the contingencies during six daily sessions, each 15 min in duration, and each separated by an intersession interval of 3 hr and 45 min. During the intersession intervals, the cue light remained off and no food was available. The onset of each session was signaled by the illumination of the cue light; failure of the cue light to be reilluminated 15 min after the onset of the session signaled the end of the session. Phase changes were made only when a visual inspection showed that relatively stable baselines had been achieved.

Phase 1. In Phase 1, the same conditions

present during Phases 1 and 3 of Experiment 1 prevailed except that the rat remained in the operant chamber after each of the first five daily sessions. The onset of the cue light signaled the start of a CRF component and a food pellet was delivered for the first lever press, accompanied by a brief offset of the cue light. Subsequent lever presses with IRTs less than 1 s (saves) were also followed by a brief offset of the cue light and the delivery of a food pellet. The cue light was extinguished, signaling the start of a 10-s EXT component, 1 s after the last lever press in CRF. At the end of the 10-s EXT period, the cue light was reilluminated to signal the onset of the next CRF component.

Phase 2. In Phase 2, exactly the same conditions prevailed except that saves had no immediate stimulus consequences. That is, only the initial CRF lever press was followed by the delivery of a food pellet, accompanied by the offset of the cue light. With the cue light remaining off, additional lever presses with

Table 2

Experiment 2: phase means based on the last 10 sessions in each phase. Data are sessional totals, except in the case of mean saves. Standard errors are in parentheses.

Rat	Phase	Lever presses	Total saves	Mean saves	CRF cycles	Food pellets
5	1	135.7	79.9	1.37	55.8	135.7
		(47.7)	(31.9)	(0.31)	(16.5)	(47.7)
	2	94.3	29.0	0.48	65.3	65.3
		(15.0)	(13.0)	(0.27)	(11.2)	(11.2)
	3	146.9	78.7	1.15	68.2	146.9
		(12.5)	(9.8)	(0.13)	(4.5)	(12.5)
	4	108.4	37.0	0.53	71.4	71.4
		(13.4)	(15.3)	(0.24)	(3.0)	(3.0)
6	1	82.2	29.9	0.55	52.3	82.2
		(21.1)	(12.2)	(0.15)	(9.8)	(21.1)
	2	75.2	11.7	0.19	63.5	63.5
		(10.6)	(9.4)	(0.17)	(6.1)	(6.1)
	3	79.4	20.7	0.35	58.7	79.4
		(13.0)	(7.4)	(0.11)	(8.2)	(13.0)
	4	68.1	7.1	0.11	61.0	61.0
		(17.6)	(4.5)	(0.06)	(14.8)	(14.8)

IRTs less than 1 s (saves) were not followed by food, but served only to postpone the onset of the 10-s EXT period. The EXT component, which was not otherwise signaled, began 1 s after the last lever press. The reillumination of the cue light 10 s later signaled the start of a new CRF component.

Phase 3. Phase 3 was a reversal to the conditions of Phase 1 with saves followed by food and brief cue light offset.

Phase 4. Phase 4 was a reversal to the conditions of Phase 2 with saves only counted.

RESULTS

The rats usually responded on all six daily sessions. The data, in the form of mean saves (saves divided by CRF components) as a function of sessions, are presented in Figure 2. Both rats made a substantial number of mean saves when saves were followed by food in Phases 1 and 3. The mean saves declined dramatically in Phases 2 and 4, however, when saves were not followed by food pellets. Because there was no evidence of within-day trends, the between-day breaks are not shown in Figure 2 in the interests of clarity. More complete data appear in the form of means for the last 10 days of each phase in Table 2. These data show that in addition to mean saves, total saves, lever presses, and, of course, food pellets delivered, all declined when saves were no longer rein-

forced. The number of CRF cycles, however, was essentially unchanged across phases for both rats.

DISCUSSION

The results of Experiment 2 suggest that the saves observed in Experiment 1 were more than mere behavioral momentum or the result of generalized motivational excitement engendered by the CRF schedule. The fact that saves did not disappear entirely during extinction does suggest that saves were to a small extent caused by something other than reinforcement. The fact that the rate of saves was considerably higher when saves were reinforced, however, suggests that the saves observed in Experiment 1 are attributable primarily to the contingency that reinforces them. This is important if the effect is to be related to self-control. Making choices between eating the current cache of pellets in the tray and pressing the lever to augment the cache implies a response to a contingency, not merely response overrun.

Other control conditions might also provide important information relevant to the effect being reported here. For example, a comparison of the number of saves made with and without the cue light offset used in the present series of studies would provide information about the role of conditioned reinforcement in controlling saves.

Table 3

Experiment 3: phase means based on the last five sessions in each phase. Data are sessional totals, except in the case of mean saves. Standard errors are in parentheses.

Rat	Phase	Lever presses	Total saves	Mean saves	CRF cycles	Food pellets
2	1	43.4 (1.4)	22.4 (1.4)	1.07 (0.10)	21.0 (1.1)	43.4 (1.4)
	2	24.6 (9.8)	9.8 (5.3)	0.58 (0.32)	14.8 (4.8)	35.8 (15.2)
	3	41.2 (4.4)	20.2 (4.3)	0.96 (0.20)	21.0 (0.7)	41.2 (4.4)
3	1	56.4 (2.4)	34.8 (2.1)	1.61 (0.09)	21.6 (0.5)	56.4 (0.4)
	2	31.6 (4.1)	14.0 (2.6)	0.80 (0.15)	17.6 (2.2)	53.2 (6.5)
	3	46.4 (3.6)	27.2 (2.4)	1.42 (0.10)	19.2 (1.5)	46.4 (3.6)

EXPERIMENT 3

Allison (1983) suggested a study in which the effects of the behavioral equivalent of interest might be examined. He suggested that if banked reinforcers (represented by increments to a counter) increased in number when left in an account instead of being withdrawn for consumption, the rate at which reinforcers were banked might be expected to increase. Historically, increased interest rates have been used to encourage self-control in the form of saving, rather than spending, money. Although the present paradigm is quite different from that suggested by Allison, it seemed to be a likely candidate for such a manipulation in view of the banking procedure used in Phases 2 and 4 of Experiment 1. In the present experiment, the effect of paying interest on the pellets banked by saves was examined. It was predicted that progressively increasing the number of pellets banked for successive saves would lead to an increased rate of saves.

METHOD

Subjects and Apparatus

The same 2 albino Wistar rats used in Experiment 1 were used in the present experiment. As in Experiment 1, they were restricted to 80% of their ad-lib weights, given ad-lib water, and housed in individual cages.

The same apparatus used in the first experiment was employed in the present experiment.

Procedure

The general procedure was similar to that utilized in Experiments 1 and 2 except that in the present experiment the session duration was reduced to 5 min. Both rats in Experiment 1, and Rat 5 in Phases 1 and 3 of Experiment 2, earned over 100 pellets per session, and there was sometimes evidence of satiation by the end of the session. The reduction in session duration was designed to prevent this, a problem likely to increase in Phase 2 of the present study with the introduction of interest. As in the previous experiments, phase changes were made only when visual inspection showed that relatively stable baselines had been achieved.

Phase 1. As in the savings account condition used in Phases 2 and 4 of Experiment 1, during each CRF component, the first lever press extinguished the cuelight and banked a food pellet by incrementing a counter. Saves were lever presses beyond the first response in a CRF component with IRTs less than 1 s. Such lever presses precluded the onset of EXT and banked a food pellet but had no other effect. The end of a CRF component occurred 1 s after the last save (or 1 s after the first lever press if there were no saves at all) and was initiated by the sequential delivery, at 0.5-s intervals, of the total number of banked pellets during the 10-s EXT component.

Phase 2. In Phase 2 the only change was that saves earned interest. In Phase 1, each lever press banked a single pellet. In Phase 2, the number of pellets banked for each lever press was equal to N , the ordinal number of the lever press. Thus, in Phase 1 a single lever press followed by three saves earned four pellets, one for each lever press. In Phase 2, however, the same pattern of responding banked 10 pellets (one for the initial lever press, two for the first save, three for the next save, and four for the last save).

Phase 3. Phase 3 was a return to the conditions in effect in Phase 1 with each save banking a single pellet.

RESULTS

The complete data from Experiment 3 appear in Table 3, and mean saves as a function of sessions appear in Figure 3. As the figure shows, for both Rats 2 and 3, when banked pellets earned interest in Phase 2, mean saves decreased substantially from the levels maintained in Phase 1 (contrary to prediction). Fur-

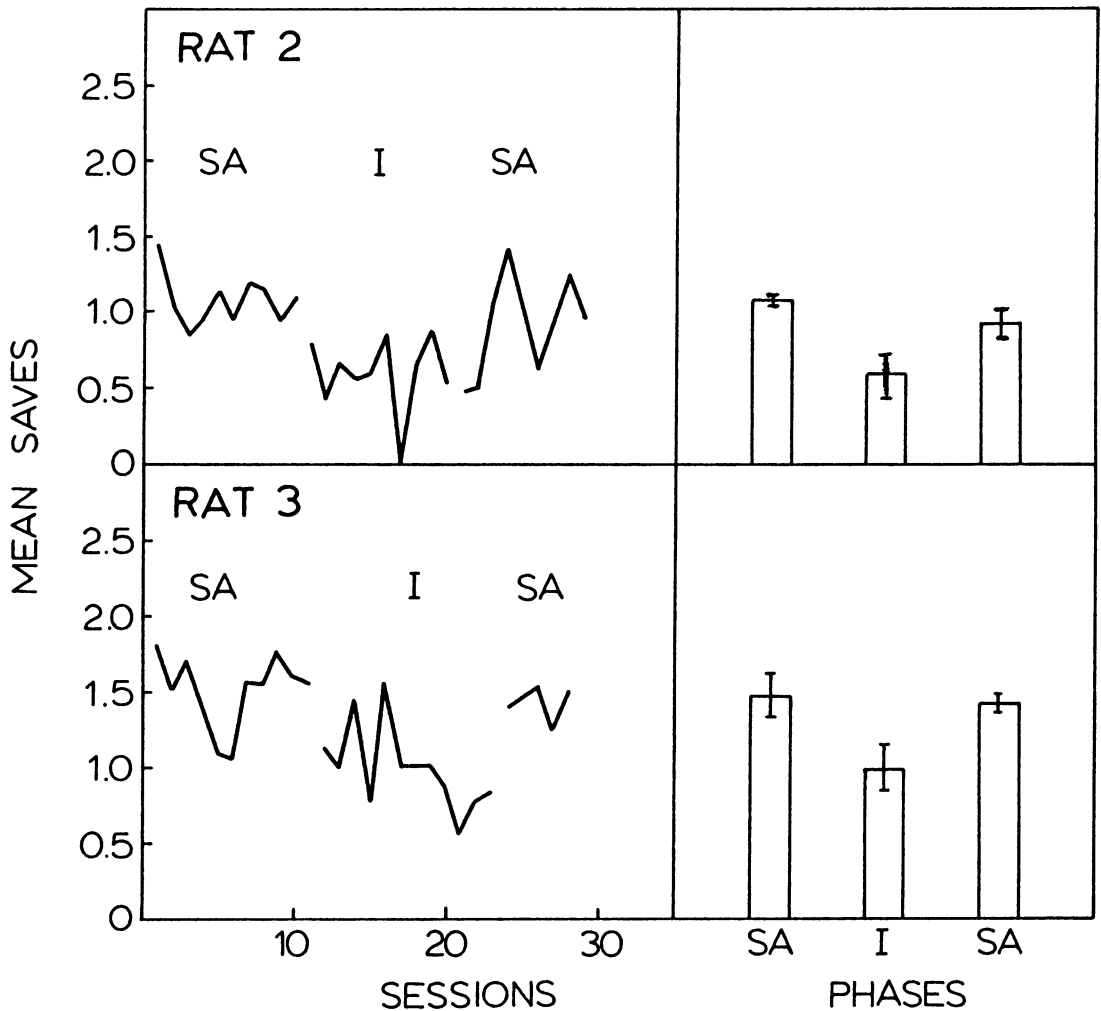


Fig. 3. Mean saves as a function of whether food pellets were simply accumulated in a savings account (SA) or earned interest in a savings account (I) in an open economy in Experiment 3. Sessional data are presented in the left panels, and the phase means from the last five sessions of each phase are presented in the right panels. The vertical lines in the right panels represent the standard errors of the mean.

thermore, on reversal to the no-interest condition in Phase 3, mean saves recovered approximately to original levels. More complete data in the form of phase means, based on the last five sessions in each phase, appear in Table 3. As the table shows, not only mean saves but also total saves, lever presses, and CRF cycles per session dropped in Phase 2 and recovered in Phase 3. Finally, Table 3 shows that there was little change in the number of food deliveries per session with the shift to interest. The only exception was a single anomalous session for Rat 2. In Session 17, Rat 2 made only six lever presses and no saves at all. Also, during the first half of Phase 2

before mean saves dropped for Rat 3, there was a slight increase in food pellets earned.

DISCUSSION

Although the rats continued to make saves during the shorter sessions used in Experiment 3 (contrary to prediction), mean saves decreased, instead of increasing, when interest was earned for saves. These data, as a whole, are consistent with the conclusion that when interest is paid, fewer saves and fewer lever presses were necessary in order to maintain a fairly constant food rate.

Hursh (1980) has pointed out that the typical operant conditioning situation such as that

used in Experiments 1, 2, and 3 represents an open economy in that food is available outside the operant setting. The principles of economics are based on closed economies in which all goods have to be obtained within the economy. The failure of the present data to conform to the prediction that interest encourages savings may have resulted from the use of an open economy in which a substantial portion (up to 85%) of the daily food intake occurred outside the operant setting. This possibility was examined in Experiment 4.

EXPERIMENT 4

The purpose of this study was to convert the open economy used in the first three experiments to a closed economy by housing rats in the operant chamber 24 hr a day. With the rats forced to obtain their entire food ration within the confines of the operant contingencies, the effect of interest on saves in a closed economy can be examined. Although the rats in Experiment 2 were kept in the chamber for 24 hr every other day, they were maintained at 80% of body weights and were fed outside the chamber to accomplish this. As a result, this did not constitute a closed economy but rather massed training.

METHOD

Subjects

Rat 2, previously used in Experiments 1 and 3, and Rat 5, previously used in Experiment 2, were used in the present experiment. Prior to the start of the experiment, they were placed on ad-lib food and water until their weights had recovered to a level close to their predeprivation weights.

Apparatus

The same apparatus used in Experiments 1 and 3 was employed in the present experiment for Rat 2, and the apparatus employed in Experiment 2 was used for Rat 5. The only change was that, in the present experiment, a water bottle was present, its 6-cm tube extending down through one of the air holes in the lid of the chamber.

Procedure

Because of the nature of this experiment, Rat 2 was tested with the entire procedure

before Rat 5 was tested in the same fashion. Conditions were the same as in the previous experiment except that at the end of each 5-min session, instead of being removed from the Skinner box and fed, the rat remained in the box during a 55-min intersession interval that was signaled by nonillumination of the cue-light. After this intersession interval, the cue-light came on again to signal the start of a new session. The rat remained in this situation 24 hr per day, being removed only occasionally for weighing and for maintenance of the box and water bottle. As in the previous experiments, phase changes were made only when visual inspection showed that relatively stable baselines had been achieved.

Phase 1. During each of the 24 daily 5-min sessions in Phase 1, a single pellet was banked by the computer for the first CRF lever press (which also extinguished the cue-light) and for each subsequent lever press with an IRT less than 1 s (save) during a CRF component. All banked pellets were delivered sequentially at 0.5-s intervals at the start of the 10-s EXT component, which followed the last lever press in a CRF component by 1 s.

Phase 2. In Phase 2, interest was earned for banked pellets. Thus, a number of pellets equal to N , the ordinal number of the consecutive lever press in a single CRF component, was banked for the initial CRF lever press and for each subsequent save.

Phase 3. Phase 3 represented a reversal to the conditions present in Phase 1 with each save banking a single pellet.

RESULTS

The rats responded in only some of the 24 daily sessions. Over all phases, Rat 2 made at least one lever press in 16.7 sessions ($SD = 3.3$), and Rat 5 responded at least once in 14.6 ($SD = 2.1$) of the 24 available daily sessions. Periodic assessments showed that both rats maintained their ad-lib weights during the course of Experiment 4.

To keep the data manageable, mean saves were calculated within each session, as in the previous experiments, and the mean of these means was then calculated each day by dividing by the number of sessions utilized that day. The resulting statistic provides a daily estimate of the average number of saves per cycle. This statistic was termed *mean daily mean saves* to distinguish it from the simple sessional means

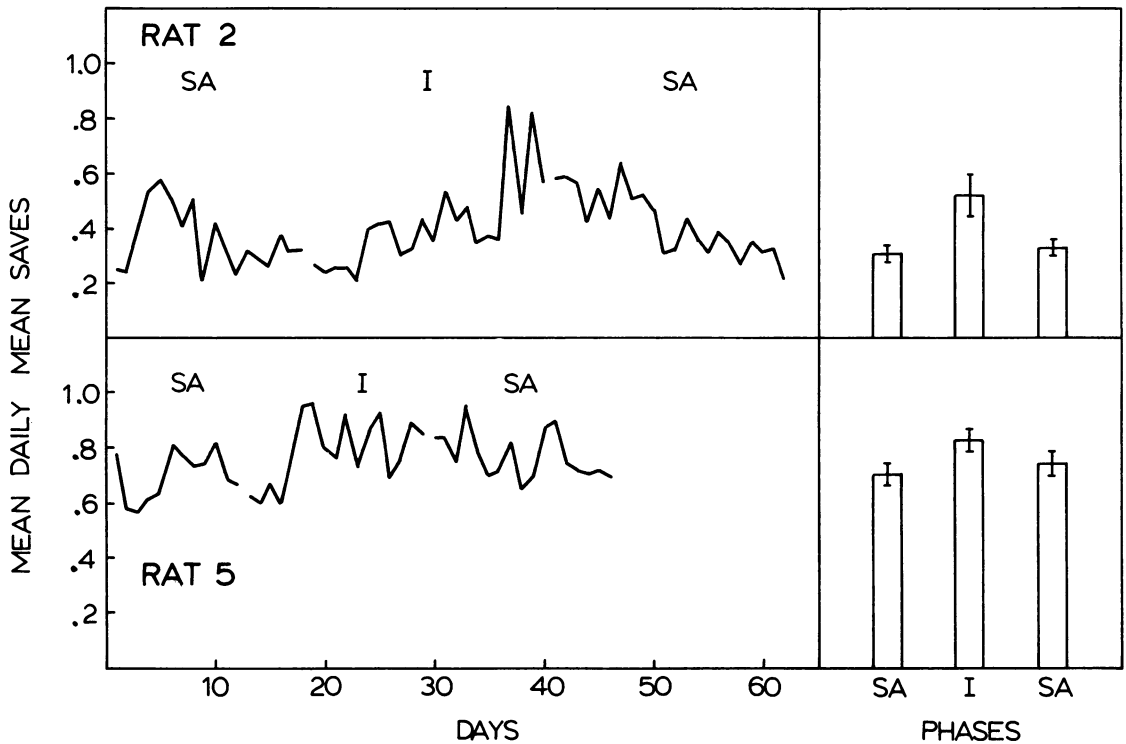


Fig. 4. Mean daily mean saves as a function of whether food pellets were simply accumulated in a savings account (SA) or earned interest in a savings account (I) in a closed economy in Experiment 4. Daily data are presented in the left panel, and the phase means from the last 10 sessions of each phase are presented in the right panel. The vertical lines in the right panel represent the standard errors of the mean.

presented in the first three experiments. The data were treated in this fashion to facilitate comparisons with the data from the first three experiments. As Figure 4 shows, the shift to interest in Phase 2 led to a substantial increase in the number of mean daily mean saves by the last 10 days of Phase 2 for Rat 2. In addition, the reversal to the condition of no interest for saves led to a nearly complete recovery of baseline by the last 10 days of Phase 3 for Rat 2. The data from Rat 5 are less convincing, but the switch to interest did lead to a slight increase in the mean daily mean saves by the last 10 days of Phase 2. The reversal, however, did not lead to a complete recovery of the original baseline.

More complete data, showing means for the last 10 days of each phase, are presented in Table 4. Again, to facilitate comparisons with the results of the first three experiments, the data are presented as daily means calculated by summing sessional values (totals, except in the case of mean saves) over daily sessions and

dividing by the number of daily sessions utilized. As these data show, the shift to interest led to generally consistent effects with respect to most of the dependent variables. For both rats, both mean daily mean saves and mean daily food pellets delivered increased following the switch to interest, whereas mean daily lever presses and mean daily cycles decreased in response to interest. At the same time, although there was little change in mean daily total saves for Rat 2, mean daily total saves actually decreased for Rat 5. However, this small decrease in total saves was more than compensated for by a large decrease in CRF cycles per session, resulting in the increase in mean saves. In addition, although Rat 2 showed no change in the number of mean daily sessions used following the shift to interest, Rat 5 utilized fewer mean daily sessions under these conditions.

DISCUSSION

The effects in Experiment 4 were not quite as strong as those in the two previous exper-

Table 4

Experiment 4: phase means based on the last 10 days in each phase. Data are daily means obtained by first summing sessional totals (sessional means in the case of mean saves) each day, and then dividing by the number of sessions utilized that day. Standard errors are in parentheses.

Rat	Phase	Mean daily					Sessions utilized
		Lever presses	Total saves	Mean saves	CRF cycles	Food pellets	
2	1	15.4 (1.5)	4.0 (0.8)	0.31 (0.06)	11.4 (0.9)	15.4 (1.5)	15.0 (3.7)
	2	13.1 (0.8)	4.5 (0.9)	0.52 (0.17)	8.6 (0.8)	18.7 (2.0)	16.8 (2.7)
	3	14.8 (1.0)	3.9 (0.6)	0.33 (0.06)	10.9 (0.7)	14.8 (1.0)	19.1 (2.4)
5	1	26.4 (1.7)	11.8 (1.2)	0.71 (0.08)	14.6 (1.1)	26.4 (1.7)	16.0 (1.6)
	2	21.2 (1.6)	9.7 (1.0)	0.83 (0.08)	11.5 (0.9)	33.9 (0.2)	13.1 (1.5)
	3	25.2 (2.2)	11.4 (1.3)	0.75 (0.08)	13.8 (1.1)	25.2 (2.2)	15.3 (1.7)

iments, particularly in the case of Rat 5. By themselves, the mean daily mean save data from Rat 5 were not very convincing. But in view of the stronger effect from Rat 2, and particularly in view of the strong effects in the opposite direction in Experiment 3, it seems safe to conclude that in the closed economy, the effect of paying interest on saves was to increase slightly the mean daily mean saves.

GENERAL DISCUSSION

The results of the present study have shown that, when offered a choice between eating the number of pellets already in the tray immediately or pressing the lever again quickly and increasing the cache, rats tended to make saves by pressing the lever. Furthermore, the results showed that this is a response to the contingency, not merely behavioral momentum. In addition, the results showed that saves were also made when no pellets were delivered until the end of the CRF component. Finally, the results showed that, in an open economy in which only some of the daily food ration was earned in the contingency, paying interest for saves by awarding an increasingly larger number of pellets for saves resulted in a reduction in mean saves. In a closed economy, however, with all the daily food being derived from the contingency, the effect of interest was to increase slightly mean saves.

Both Rachlin and Green (1972) and Mazur

(1984) have offered models based on the matching law (cf. Baum & Rachlin, 1969; Catania, 1963; Herrnstein, 1970; Logan, 1965) explaining the circumstances under which organisms will elect to forgo a smaller, more immediate, reward in favor of a larger, but more delayed, one. Rachlin and Green (1972) argued that the value of a reinforcer (V_i) is given by the hyperbolic function:

$$V_i = \frac{A_i}{D_i},$$

where V_i is the value of reward i , A_i is the size of reward i , and D_i is the delay of reward i . Plotting values of V_i for different values of D_i at two levels of A_i yields hyperbolic curves rising to infinity as the scheduled time of each reinforcement approaches. With different values chosen for A_i and D_i the curves intersect. Just before the scheduled time of delivery of the small reinforcer, the value of the small reinforcer is greater than that of the delayed and larger reinforcer, and so the model predicts that it will be chosen. At times well in advance of the scheduled delivery of the immediate reinforcer, however, the larger reinforcer has a greater value than the smaller one, and the model predicts that if the choice is made at that time, the larger will be chosen. As discussed earlier, a number of studies have found that forcing a choice well before the more immediate and smaller reinforcer favors self-control.

Based on the results of various studies (e.g., Mazur, 1984, 1986; Grossbard & Mazur, 1986; Mazur, Snyderman, & Coe, 1985), Mazur (1984) argues that the value of a reinforcer is best determined by the following function:

$$V_i = \frac{A_i}{1 + KD_i},$$

where V_i is the value of reward i , A_i is the size of reward i , K is a free parameter, and D_i is the delay of reward i . The main difference between this model and that presented by Rachlin and Green is the value 1 in the denominator, which produces a finite value for V_i at $T = 0$. As a result, the curves for two different-sized reinforcers do not necessarily intersect and the model does not always predict failure of self-control at $T = 0$. This latter point is important in view of the self-control observed in the present study when $T = 0$. In addition, the parameter K permits fitting the model to specific data.

Because of differences between the present paradigm and those used to generate and test models like that of Rachlin and Green (1972) and Mazur (1984), one must proceed cautiously in relating the present data to such models. In addition to the features mentioned earlier (e.g., asymmetry), the present paradigm is different from the more traditional approaches in using very short sessions and very high rates of reinforcement. As a result, there may have been within-session satiation effects. Also, because the data obtained in the present study are not parametric in nature, an exact fit of the data to Mazur's model is not appropriate. In general terms, however, his model explains the shift from self-control to impulsivity as the increments to the cache become a smaller and smaller proportion of the total cache. As presented, Mazur's model predicts that in the interest condition, more saves will be made. With each successive save, the cache grows by a proportionately greater amount in the interest condition than in the basic savings account condition. For example, the first save tripled the cache in the interest condition, whereas the first save merely doubled the size of the cache in the original savings account condition. As a result, the initial divergence of the curves is greater in the interest condition, and the crossover point, at which the value of the smaller reward becomes greater at $T = 0$, is reached only after more saves have

been made. In the present paradigm, however, a large cache takes more time to consume than the time-based large rewards typically used in self-control studies. As a result, it is possible that the value of increasingly larger rewards should be discounted due to the consumption time required. One way to do this would be to raise A_i in Mazur's model to a fractional power. As the size of the fractional power is reduced from 1.0, the model first predicts more, then the same number, and finally fewer saves in the interest condition than in the savings account condition. The present data thus require that A_i be raised to a relatively smaller fractional power to account for the outcome in the open economy of Experiment 3 in which interest led to fewer saves. To account for the increased saves produced by the interest manipulation in Experiment 4, on the other hand, the discounting of large rewards must be a good deal less and hence the fractional power must be relatively larger. The present data suggest that an examination of self-control and impulsivity in open and closed economies using more traditional paradigms might also be instructive.

The manipulations in Experiments 3 and 4 were based on general economic principles; some discussion of the results in terms of economics is thus warranted. One of the paramount principles in economic theory is the demand law (Allison, 1983). This law states that with most goods, when the price of the good is decreased, the demand increases. That is, more goods are purchased at the new price. If the percentage increase in consumption exceeds the percentage decrease in price the demand is called *elastic demand* (Allison, 1983) and tends to occur with nonessential goods. With some goods, however, the percentage increase in consumption is lower than the percentage decrease in price. This tends to happen with essential goods, and the failure of their consumption to respond significantly to the price drop is referred to as *inelastic demand* (Allison, 1983).

As mentioned earlier, Hursh (1978, 1980) has made a distinction between operant results obtained in open economies and those generated by closed economies. In particular, he has argued that, in the open economy represented by the typical operant conditioning experiment, demand for food is elastic because it is nonessential, extracontingency food being

available. In a closed economy in which all food is earned within the contingency, however, demand for now-essential contingency-derived food becomes inelastic, according to Hursh.

It is possible to view the manipulation used in Experiments 3 and 4 as a price reduction rather than as interest. In behavioral economics, price is expressed as the cost of food in terms of the number of responses required. Reference to Tables 3 and 4 reveals that, averaged over all 4 rats, the mean percentage reduction in the price of food (responses per reinforcer) was 37% in moving from the savings account condition to the interest condition. However, the resulting mean percentage increase in food consumed per session was essentially 0% in Experiment 3 and only about 25% in Experiment 4. Thus, in both Experiments 3 and 4, the rats showed inelastic demand for food because the percentage increase in consumption failed to exceed the percentage decrease in price, although it came closer in the closed economy of Experiment 4.

The discounting referred to in connection with Mazur's model is reminiscent of the principle of diminishing utility (Allison, 1983). This principle states that with successive increments, the utility or value of a good is increasingly diminished. One might expect a more rapidly diminishing utility for food in an open economy in which food is nonessential. Similarly, one might expect a less rapidly diminishing utility for the relatively more essential food in a closed economy. The results of Experiments 2 and 3 seem to be consistent with this principle.

Timberlake and Peden (1987) recently have questioned the usefulness of the open-closed economy distinction, attributing the effects instead to differences in the densities of reward between so-called open and closed economies or to deprivation levels, or both. They have shown that, regardless of whether the economy is open or closed, increases in the available rate of reinforcement, when density is high to begin with, lead to decreases in response rate and inelastic demand, as there is little change in the rate of food consumption. In the present studies, the highest price paid for food was CRF, so the density of reinforcement was very high in spite of the 10-s extinction periods between CRF components. As a result, the failure to show elasticity of demand in Ex-

periments 3 and 4 is consistent with the findings of Timberlake and Peden and inconsistent with those of Hursh (1978, 1980). The relationship between demand and the occurrence of saves as defined in the present research will have to be established through further research.

The results of the present study demonstrate an interesting variation of the self-control paradigm. Before it can be offered as a useful paradigm, however, the problem of asymmetry of response will have to be solved. The interest manipulation has, however, provided data challenging the models of both Rachlin and Green (1972) and Mazur (1984). Furthermore, the analogue of interest payments on savings accounts provides additional data relevant to an analysis of behavior in terms of behavioral economics. Finally, the data provide further evidence questioning the universality of the open-closed economy distinction made by Hursh (1980) and support the recent position of Timberlake and Peden (1987) regarding the role of density of reinforcement in elasticity of demand.

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